# EEC2146: Electronic Circuits and Measurements


Prepared by:
Dr. Hossam Kasem

Email:
hossam.kasem@f-eng.tanta.eg
hossamkasem1@gmail.com

# EEC2146: Electronic Circuits and Measurements

LEC: 4
Amplifier Frequency Response

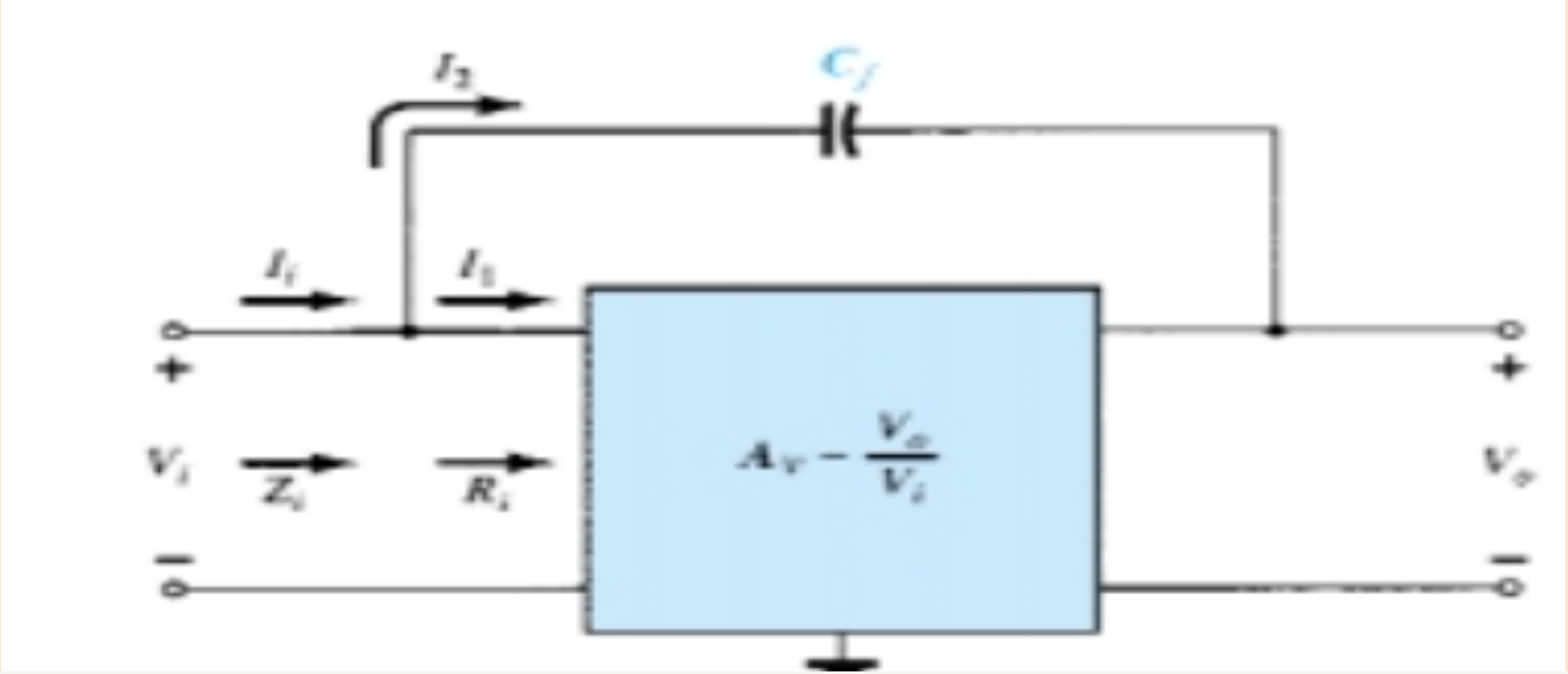
# Amplifier Frequency Response

## Objectives and outline:

- Analyze the high-frequency response of an amplifier
- Analyze an amplifier for total frequency response
- Analyze multistage amplifiers for frequency response
- Measure the frequency response of an amplifier

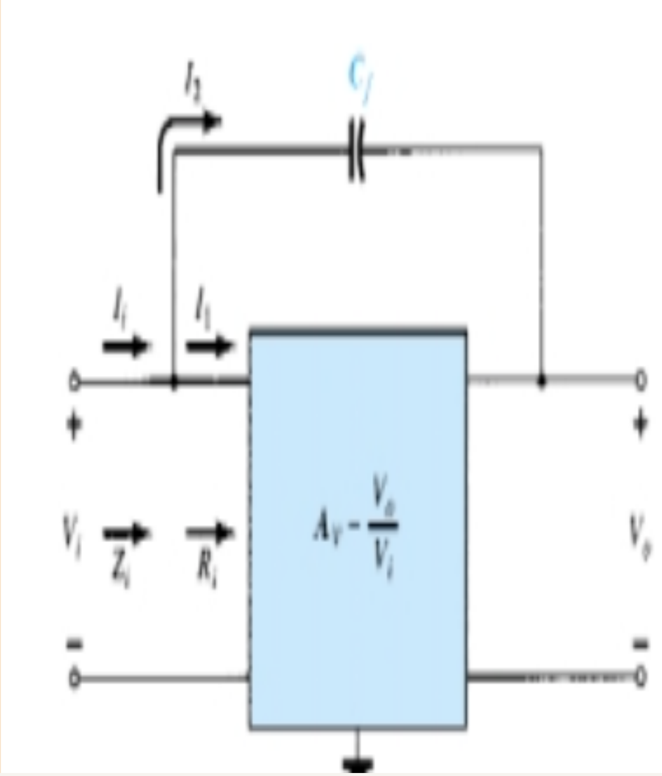
# Amplifier Frequency Response

## MILLER EFFECT CAPACITANCE :



# Amplifier Frequency Response

## MILLER EFFECT CAPACITANCE :



Applying Kirchhoff's current law gives

$$I_i = I_1 + I_2$$

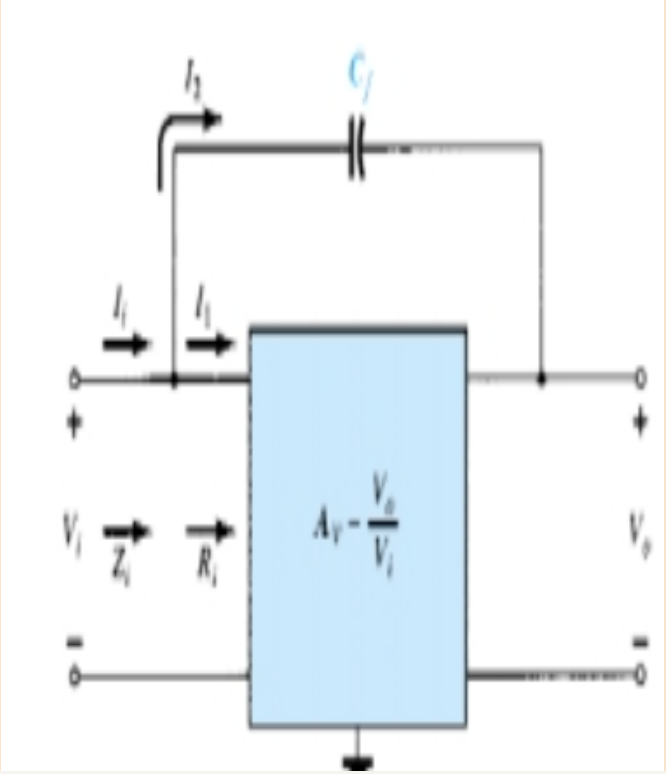
$$I_i = \frac{V_i}{Z_i}, \qquad I_1 = \frac{V_i}{R_i}$$

$$I_2 = \frac{V_i - V_o}{X_{C_f}} = \frac{V_i - A_v V_i}{X_{C_f}} = \frac{(1 - A_v)V_i}{X_{C_f}}$$

Substituting, we obtain

# Amplifier Frequency Response

## MILLER EFFECT CAPACITANCE :




$$\frac{V_i}{Z_i} = \frac{V_i}{R_i} + \frac{(1 - A_v)V_i}{X_{C_f}}$$

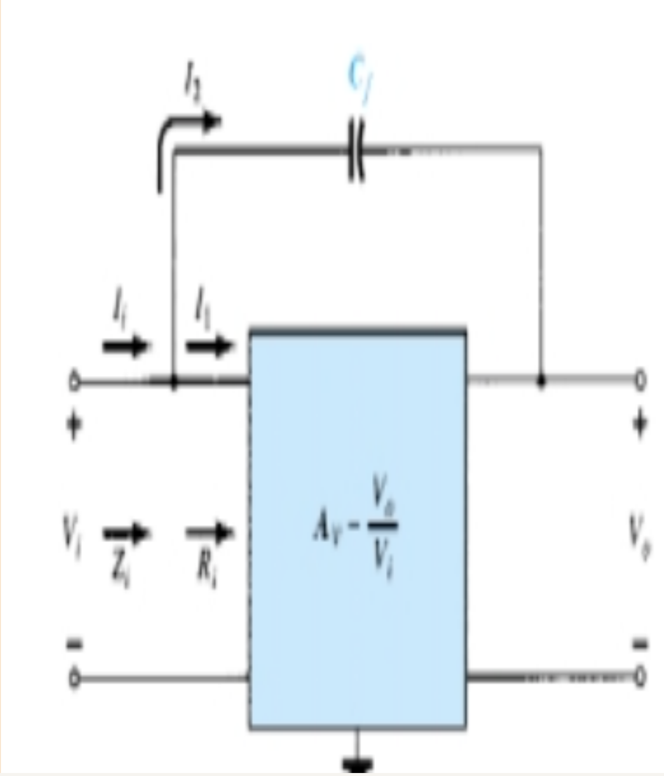
$$\frac{1}{Z_i} = \frac{1}{R_i} + \frac{1}{X_{C_f}/(1 - A_v)}$$

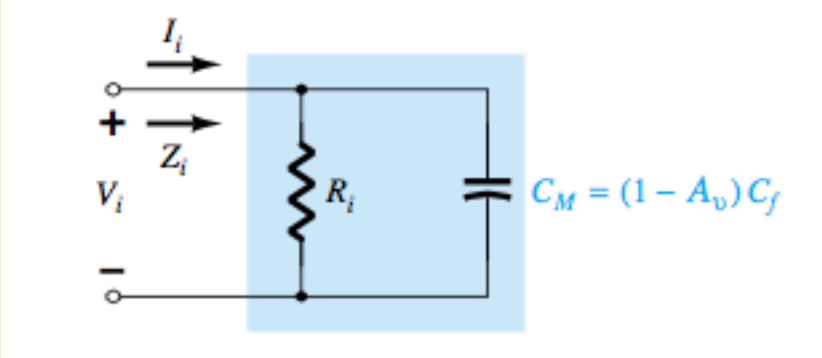
$$\frac{X_{C_f}}{1 - A_v} = \frac{1}{\omega \underbrace{(1 - A_v)C_f}_{C_M}} = X_{CM}$$

$$\frac{1}{Z_i} = \frac{1}{R_i} + \frac{1}{X_{C_M}}$$

# Amplifier Frequency Response

## MILLER EFFECT CAPACITANCE :



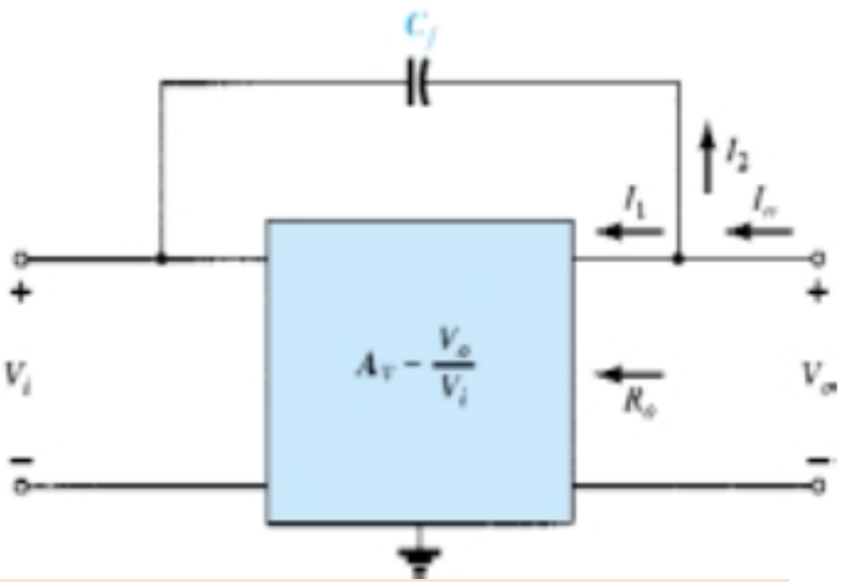




$$\boxed{C_{M_i} = (1 - A_v)C_f}$$

Dr.Hossam kasem
Electronics and Electrical Comm. Dept.

# Amplifier Frequency Response

## MILLER EFFECT CAPACITANCE :




$$I_o = I_1 + I_2$$

$$I_1 = \frac{V_o}{R_o} \quad \text{and} \quad I_2 = \frac{V_o - V_i}{X_{C_f}}$$

$$I_o \cong \frac{V_o - V_i}{X_{C_f}}$$

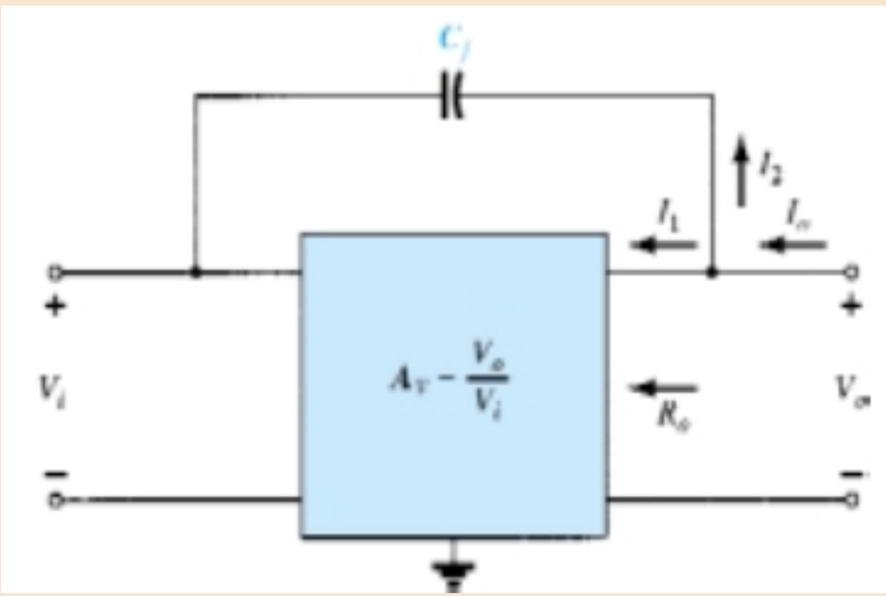
Substituting $V_i = V_o/A_v$ from $A_v = V_o/V_i$ will result in

$$I_o = \frac{V_o - V_o/A_v}{X_{C_f}} = \frac{V_o(1 - 1/A_v)}{X_{C_f}}$$

$$\frac{I_o}{V_o} = \frac{1 - 1/A_v}{X_{C_f}}$$

# Amplifier Frequency Response

## MILLER EFFECT CAPACITANCE :




$$\frac{V_o}{I_o} = \frac{X_{C_f}}{1 - 1/A_v} = \frac{1}{\omega C_f (1 - 1/A_v)} = \frac{1}{\omega C_{M_o}}$$

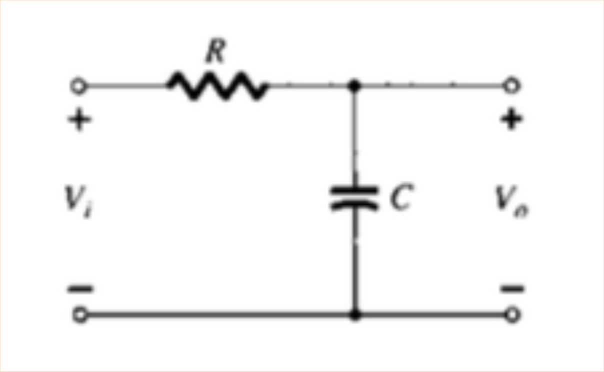
$$\boxed{C_{M_o} = \left(1 - \frac{1}{A_v}\right) C_f}$$

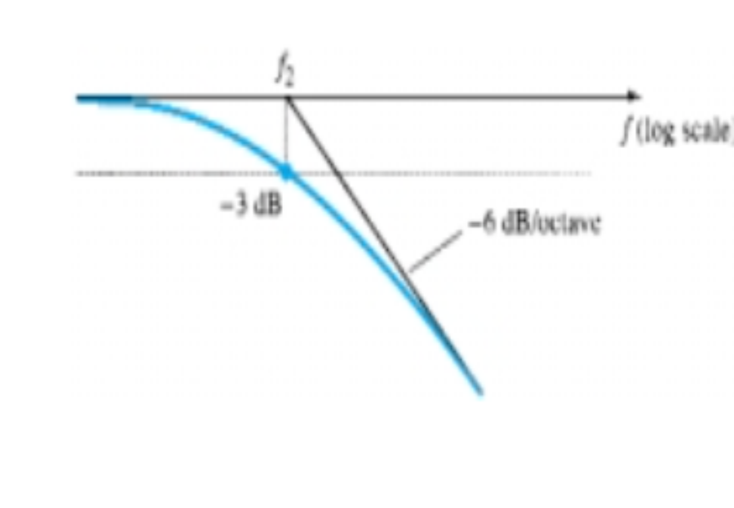
$$\boxed{C_{M_o} \cong C_f} \quad |A_v| \gg 1$$

# Amplifier Frequency Response

## High Frequency Response:

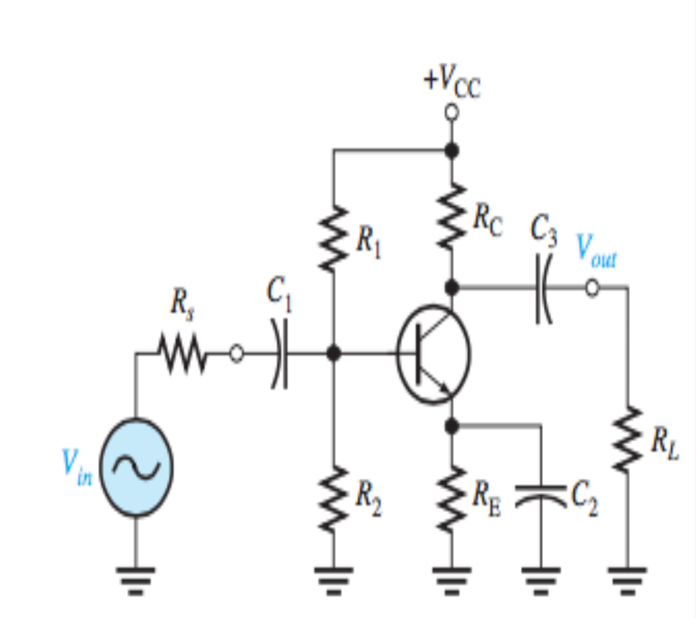
$$A_v = \frac{1}{1 + j(f/f_2)}$$

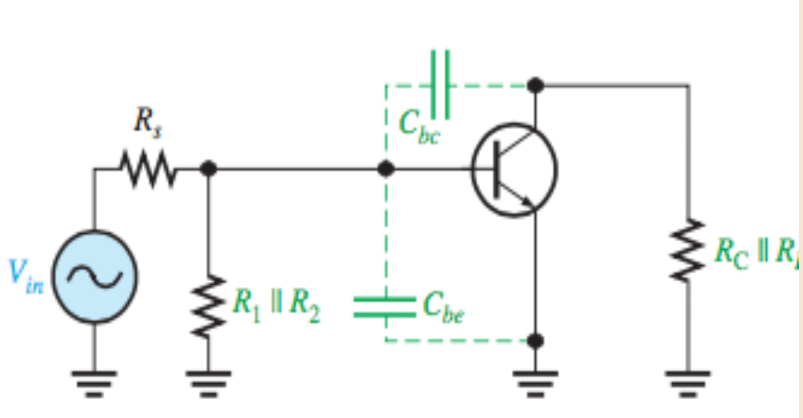


# Amplifier Frequency Response

## High Frequency Response:

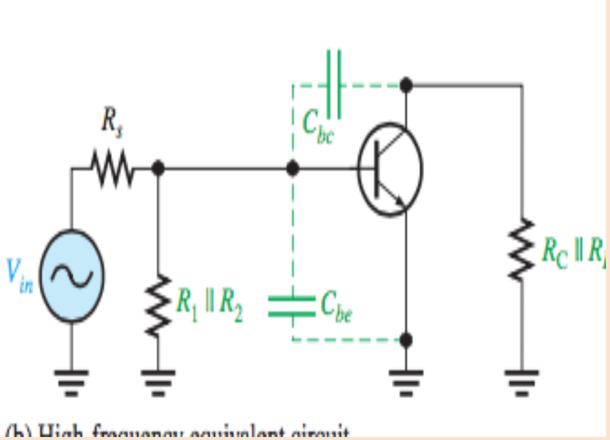



(b) High-frequency equivalent circuit

# Amplifier Frequency Response

## High Frequency Response:

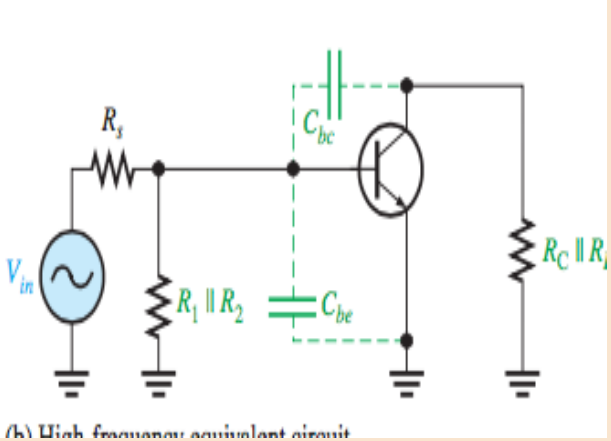


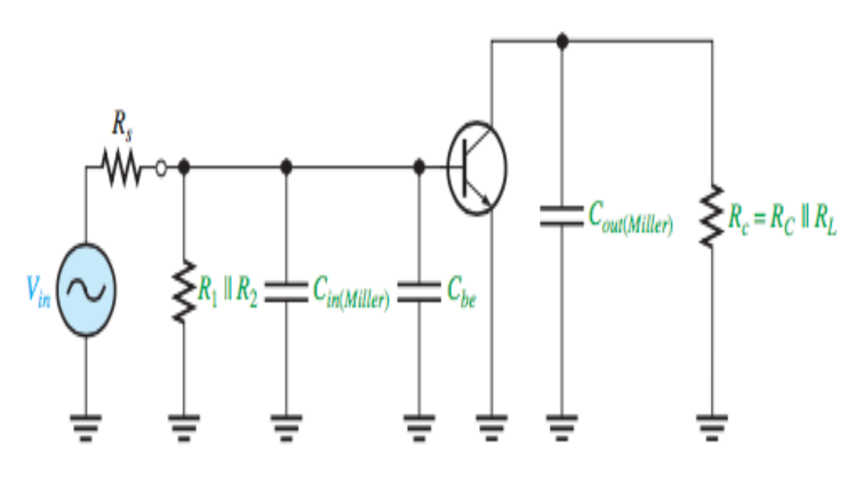

$$C_{in(Miller)} = C_{bc}(A_v + 1)$$

$$C_{out(Miller)} = C_{bc}\left(\frac{A_v + 1}{A_v}\right)$$

# Amplifier Frequency Response

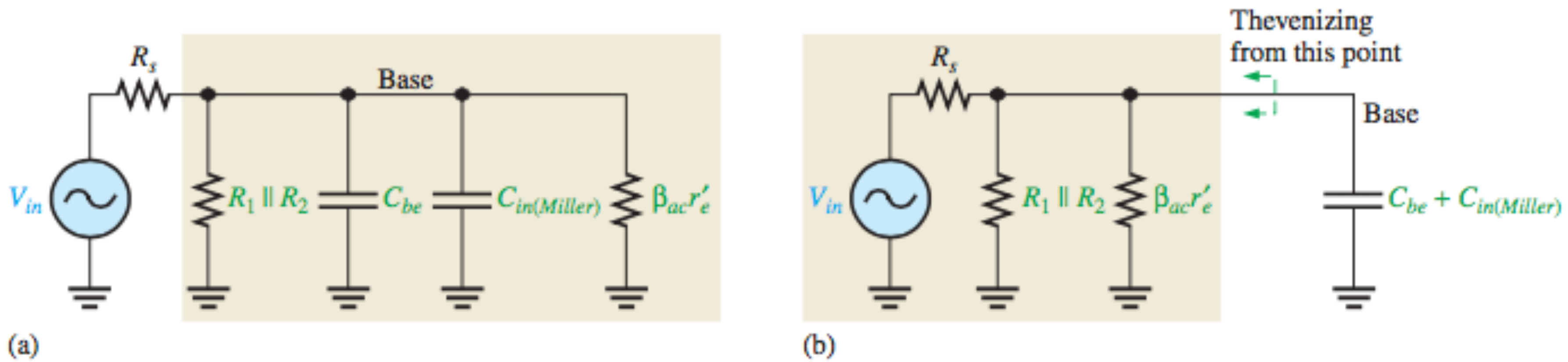
## High Frequency Response:



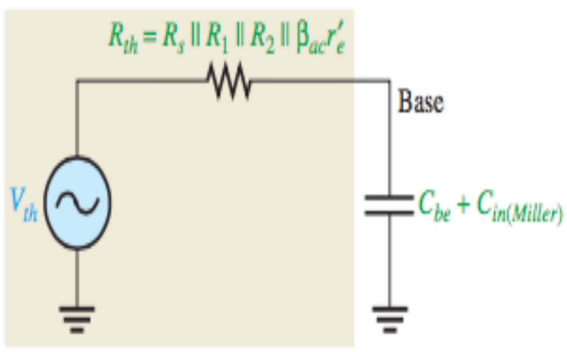
# Amplifier Frequency Response

## The Input *RC* Circuit :



# Amplifier Frequency Response

## The Input *RC* Circuit :




(c)

$$C_{tot} = C_{be} + C_{in(Miller)}$$

$$X_{C_{tot}} = R_s \parallel R_1 \parallel R_2 \parallel \beta_{ac} r'_e$$

$$\frac{1}{2\pi f_{cu\,(input)} C_{tot}} = R_s \parallel R_1 \parallel R_2 \parallel \beta_{ac} r'_e$$

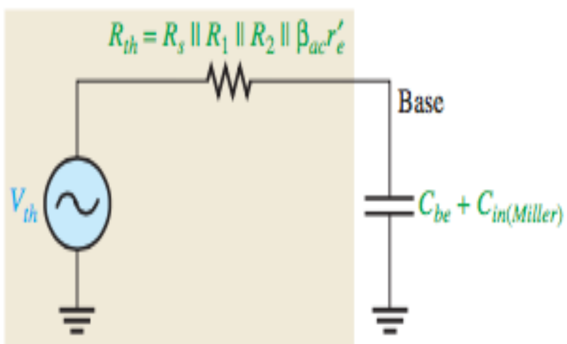
$$f_{cu(input)} = \frac{1}{2\pi (R_s \parallel R_1 \parallel R_2 \parallel \beta_{ac} r'_e) C_{tot}}$$

# Amplifier Frequency Response

## The Input *RC* Circuit :

**Phase Shift of the Input RC Circuit**

, the output of the circuit lags the input.



(c)

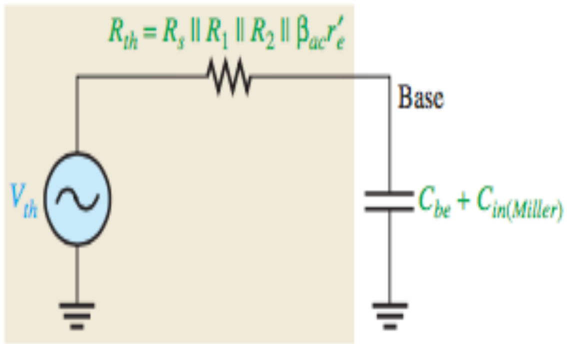
$$\theta = \tan^{-1}\left(\frac{R_s \| R_1 \| R_2 \| \beta_{ac} r'_e}{X_{C_{(tot)}}}\right)$$

# Amplifier Frequency Response

## The Input *RC* Circuit :

**Phase Shift of the Input RC Circuit**

, the output of the circuit lags the input.

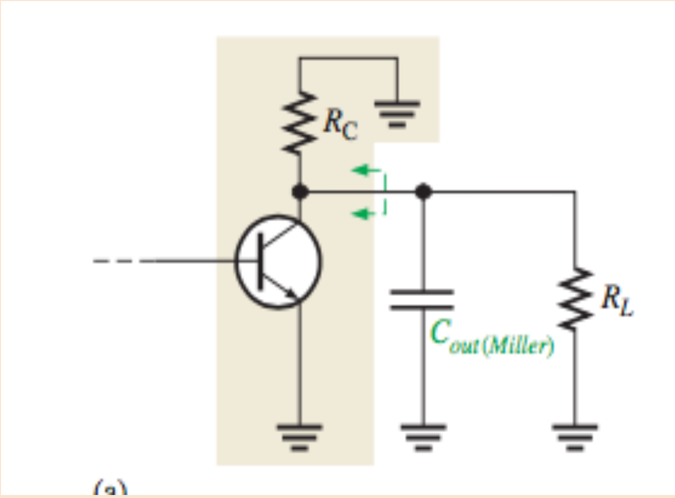


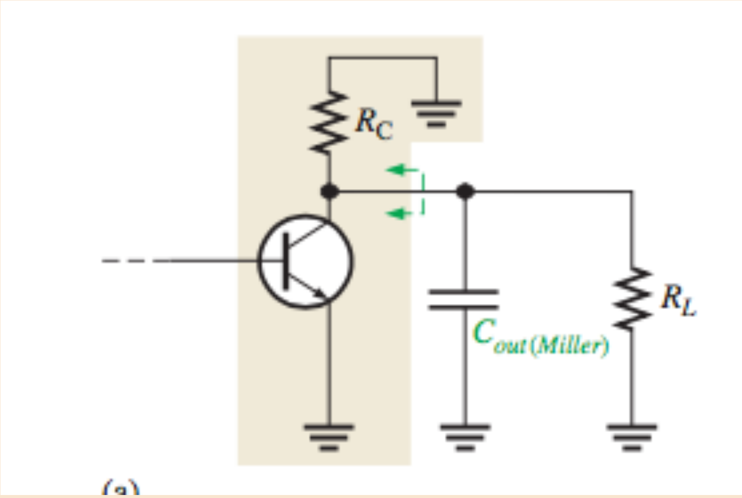
(c)

$$\theta = \tan^{-1}\left(\frac{R_s \parallel R_1 \parallel R_2 \parallel \beta_{ac} r'_e}{X_{C_{(tot)}}}\right)$$

# Amplifier Frequency Response

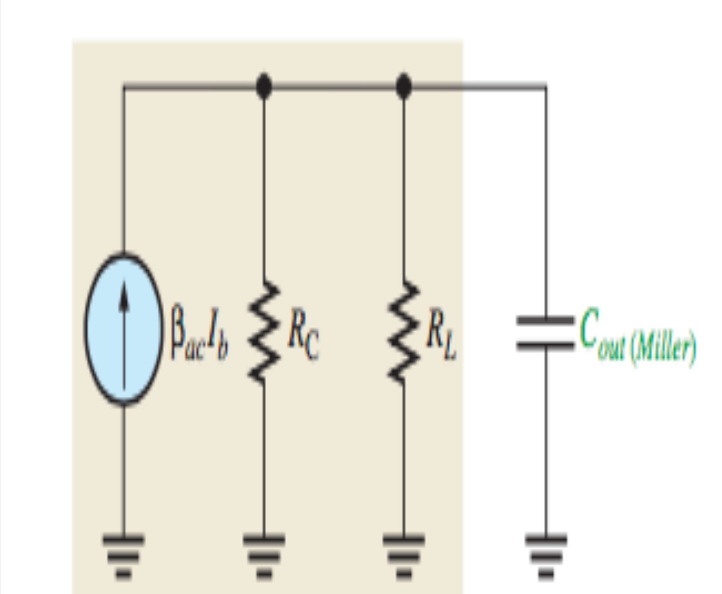
## The Output *RC* Circuit

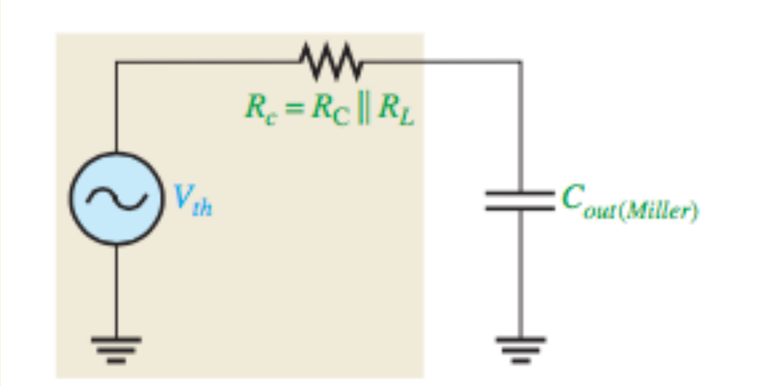


# Amplifier Frequency Response

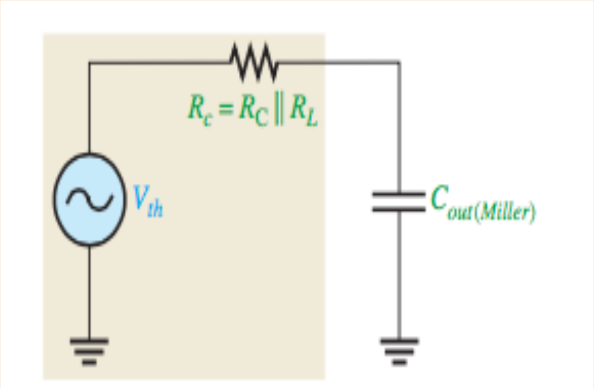
## The Output *RC* Circuit



# Amplifier Frequency Response

## The Output *RC* Circuit




$$C_{out(Miller)} = C_{bc}\left(\frac{A_v + 1}{A_v}\right)$$

$$C_{out(Miller)} \cong C_{bc}$$

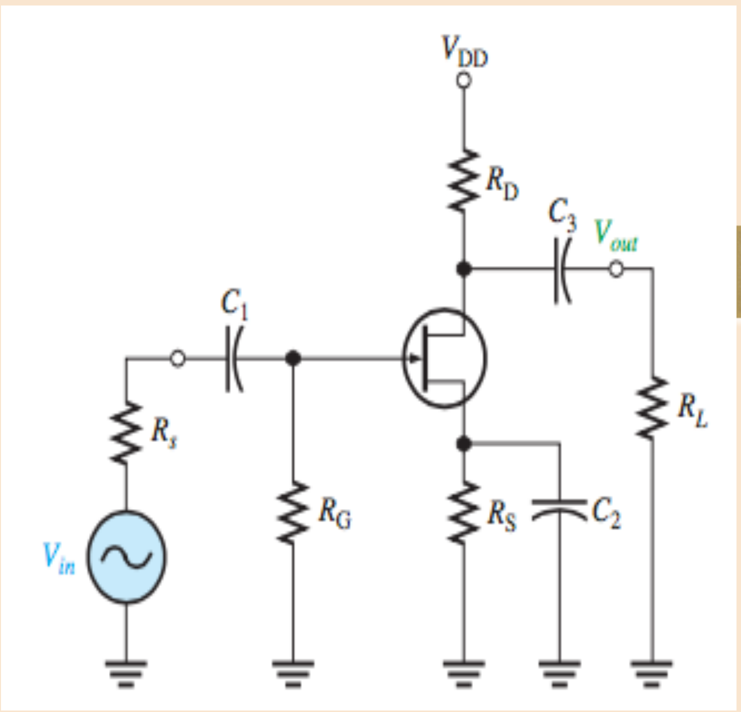
$$f_{cu(output)} = \frac{1}{2\pi R_c C_{out(Miller)}}$$

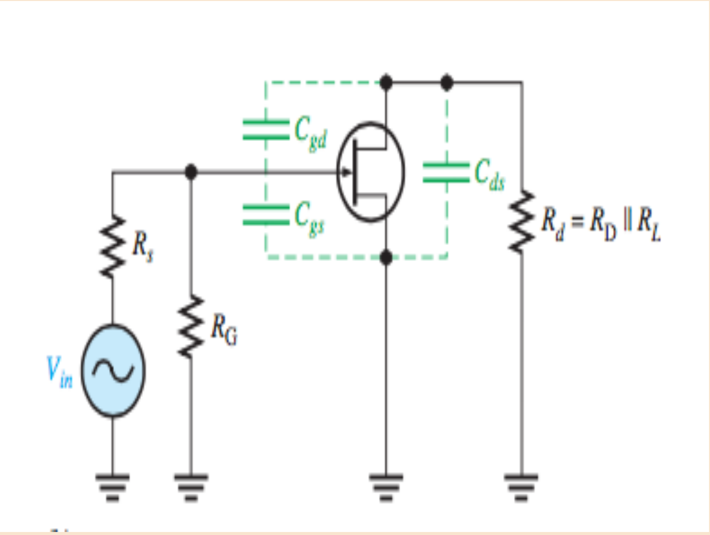
$$R_c = R_C \parallel R_L.$$

$$\theta = \tan^{-1}\left(\frac{R_c}{X_{C_{out(Miller)}}}\right)$$

# Amplifier Frequency Response

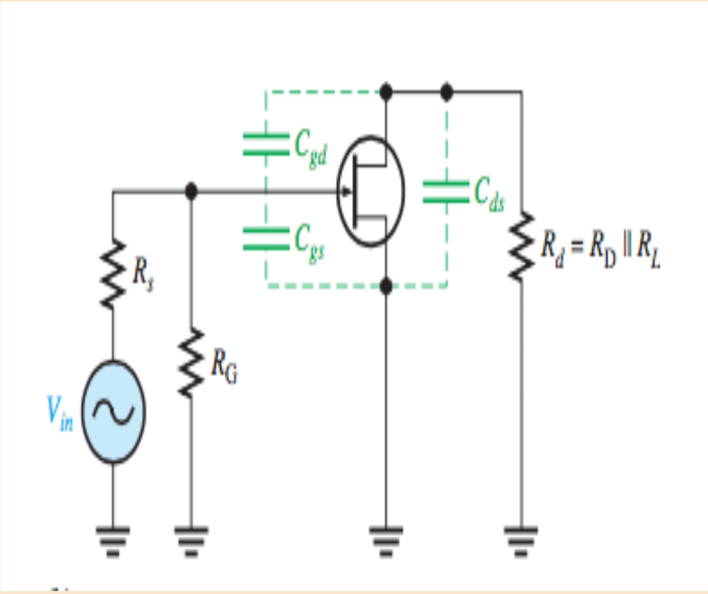
## FET Frequency Response:



# Amplifier Frequency Response

## FET Frequency Response:




$$C_{gd} = C_{rss}$$

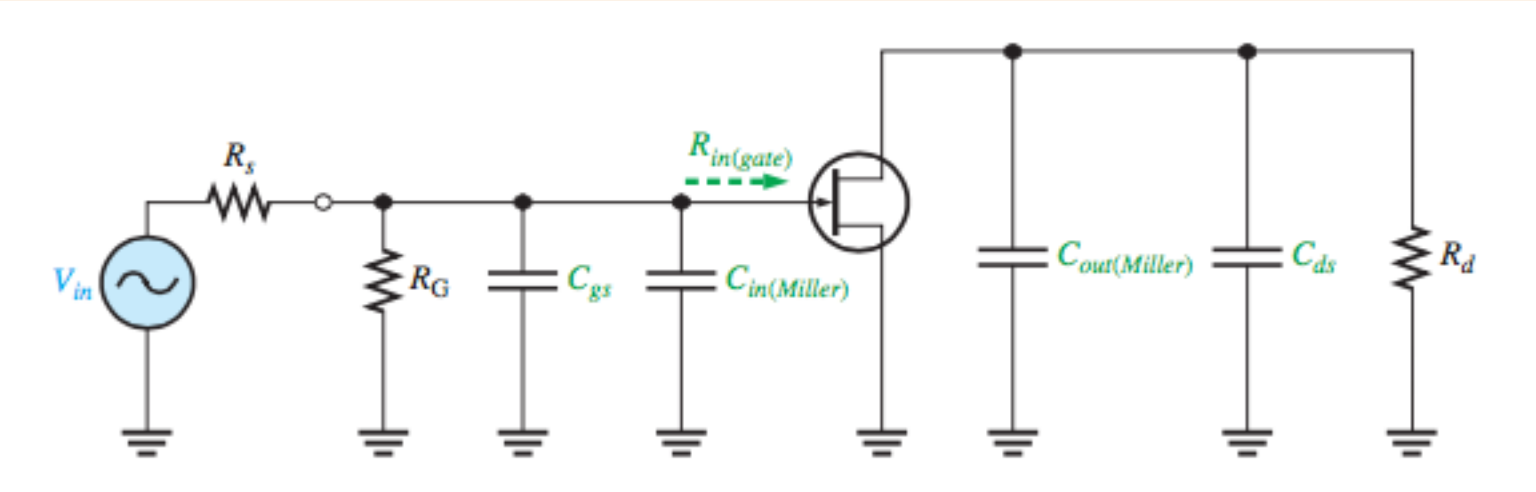
$$C_{gs} = C_{iss} - C_{rss}$$

$$C_{ds} = C_{oss} - C_{rss}$$

$$C_{in(Miller)} = C_{gd}(A_v + 1)$$

# Amplifier Frequency Response

## FET Frequency Response:

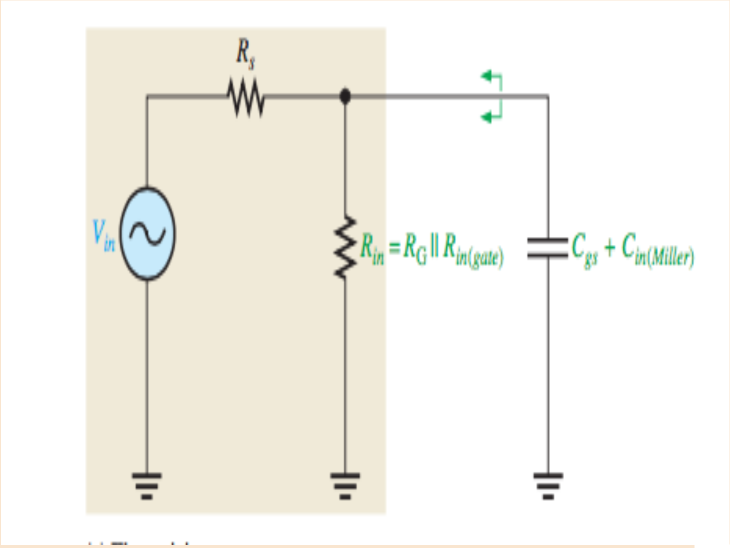


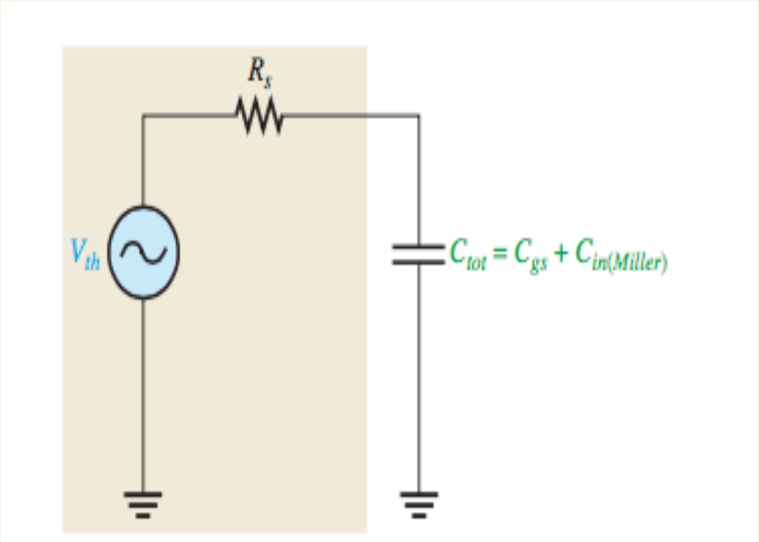

$$C_{in(Miller)} = C_{gd}(A_v + 1)$$

$$C_{out(Miller)} = C_{gd}\left(\frac{A_v + 1}{A_v}\right)$$

# Amplifier Frequency Response

## The Input *RC* Circuit

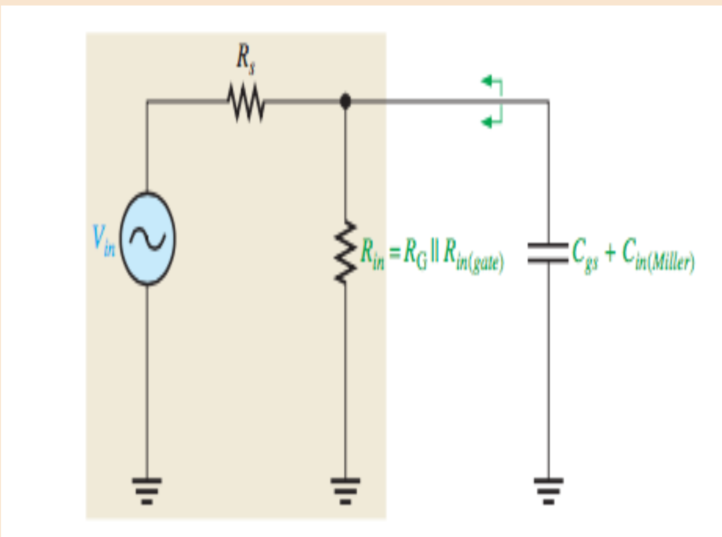


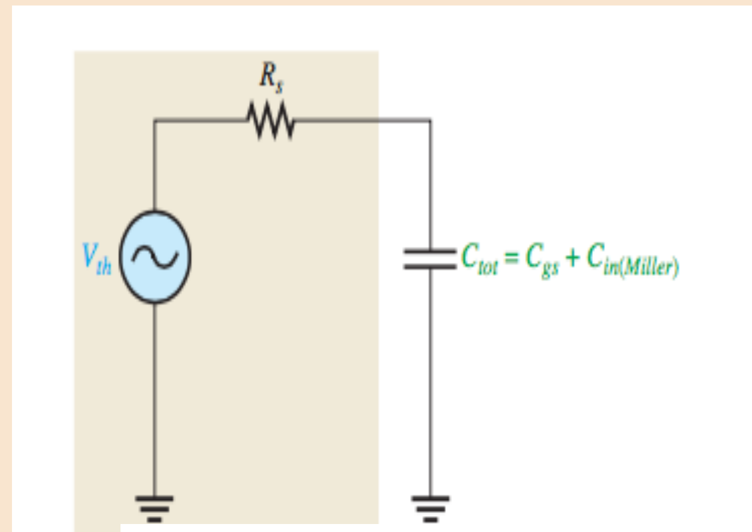




$$f_{cu(input)} = \frac{1}{2\pi R_s C_{tot}}$$

# Amplifier Frequency Response

## The Input *RC* Circuit



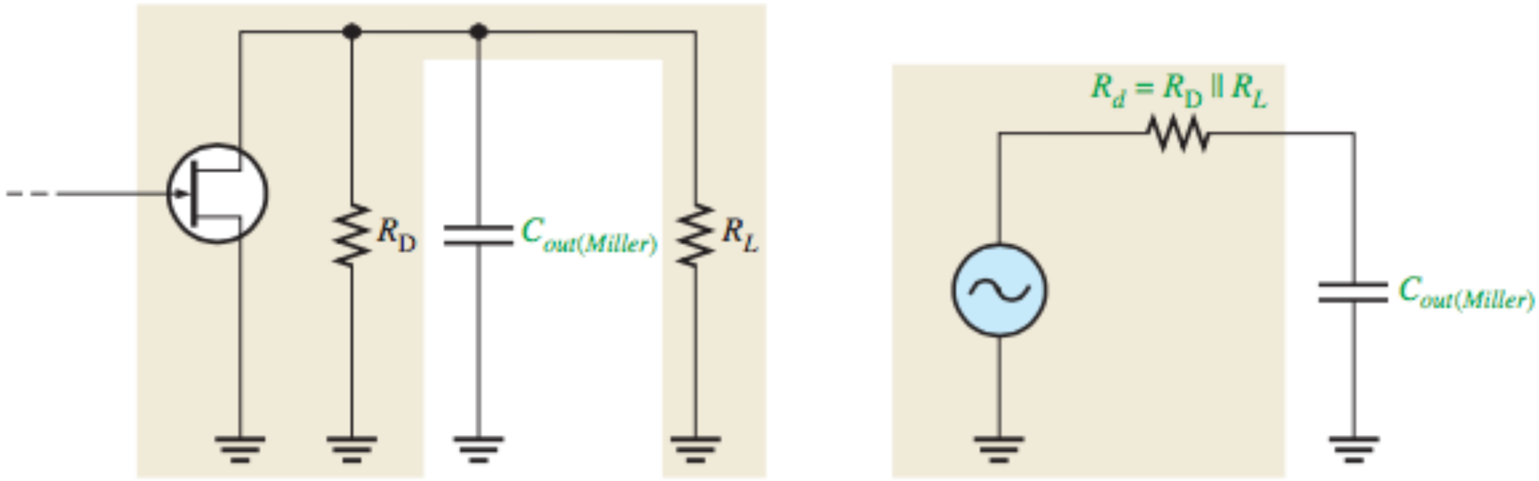

$$f_{cu(input)} = \frac{1}{2\pi R_s C_{tot}}$$

$$C_{tot} = C_{gs} + C_{in(Miller)}.$$

$$\theta = \tan^{-1}\left(\frac{R_s}{X_{C_{tot}}}\right)$$

# Amplifier Frequency Response

## The output *RC* Circuit



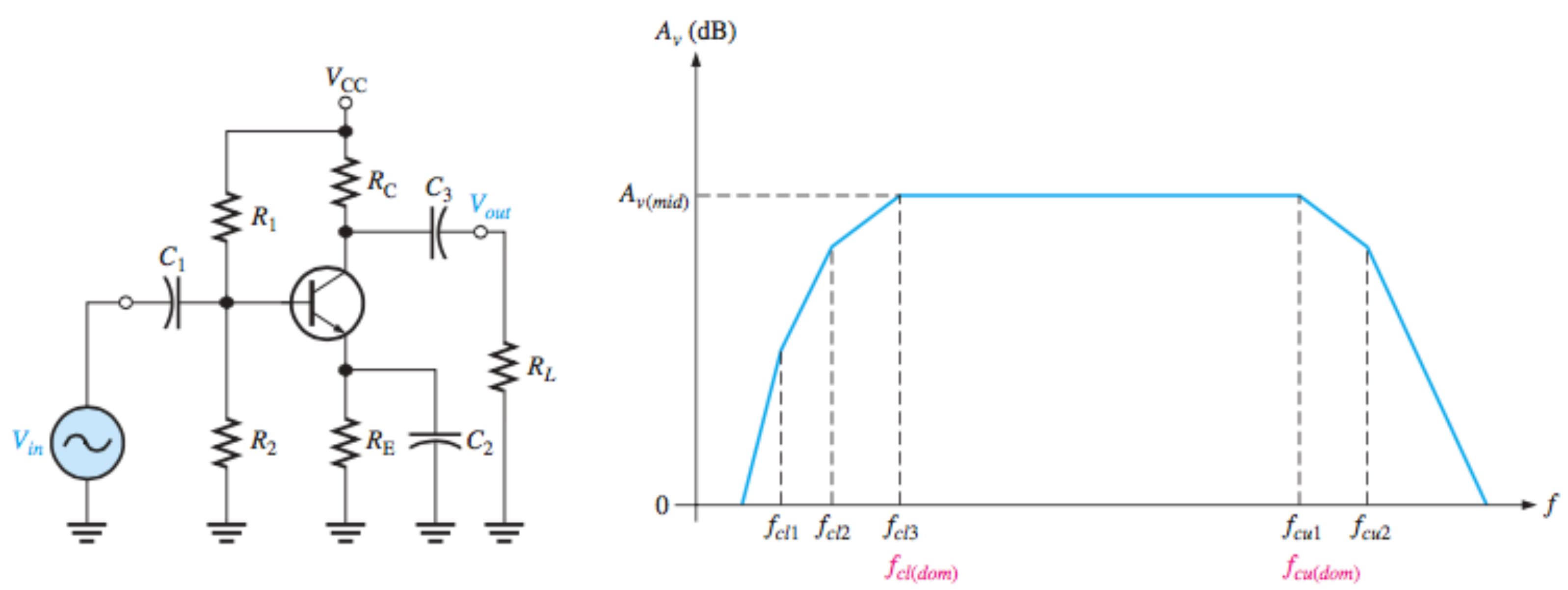

$$C_{out(Miller)} = C_{gd}\left(\frac{A_v + 1}{A_v}\right)$$

$$f_{cu(output)} = \frac{1}{2\pi R_d C_{out(Miller)}}$$

$$\theta = \tan^{-1}\left(\frac{R_d}{X_{C_{out(Miller)}}}\right)$$

# Amplifier Frequency Response

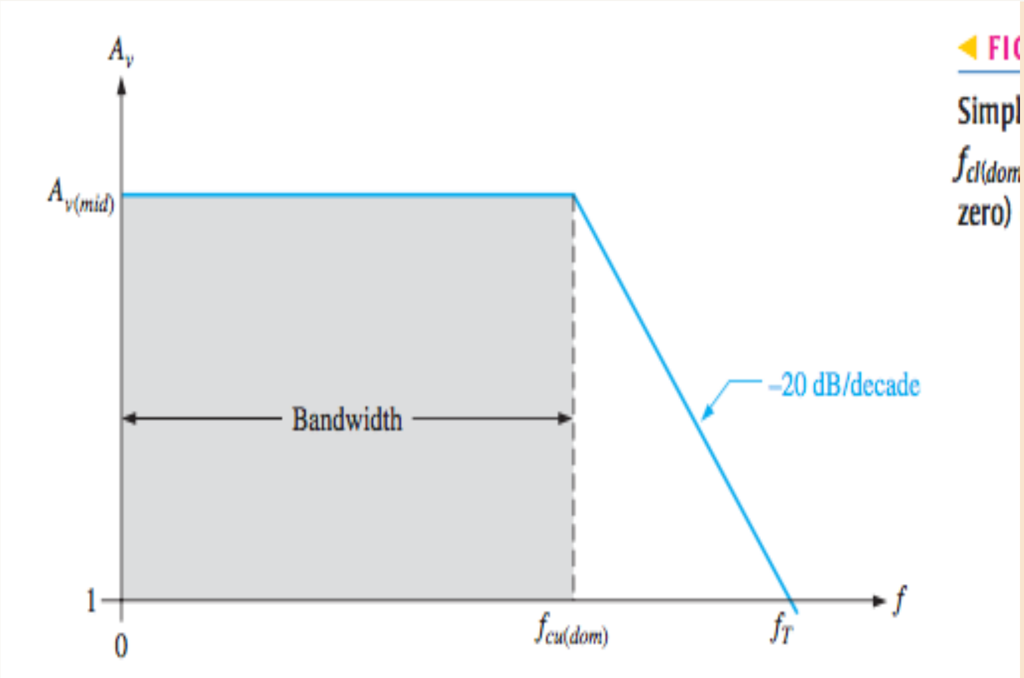
## TOTAL AMPLIFIER FREQUENCY RESPONSE




$$BW = f_{cu(dom)} - f_{cl(dom)}$$

# Amplifier Frequency Response

## Gain-Bandwidth Product




$$f_T = A_{v(mid)} BW$$

# Amplifier Frequency Response

## Multi stages Amplifier Frequency Response :

- When amplifier stages are cascaded to form a multistage amplifier, the dominant frequency response is determined by the responses of the individual stages. There are two cases to consider:

**1.** Each stage has a different dominant lower critical frequency and a different dominant upper critical frequency.

2. Eachstagehasthesamedominantlowercriticalfrequencyandthesamedominant upper critical frequency.

# Amplifier Frequency Response

## Different Frequencies :

- when the dominant lower critical frequency, $f_{cl(dom)}$, of each amplifier stage is different from the other stages, the overall dominant lower critical frequency, $f_{cl(dom)}$, equals the dominant critical frequency of the stage with the highest $f_{cl(dom)}$.
- Ideally, when the dominant upper critical frequency, $f_{cu(dom)}$, of each amplifier stage is different from the other stages, the overall dominant upper critical frequency, $f_{cu(dom)}$, equals the dominant critical frequency of the stage with the lowest $f_{cu(dom)}$.

$$BW = f'_{cu(dom)} - f'_{cl(dom)}$$

# Amplifier Frequency Response

## Equal Frequencies :

- When each amplifier stage in a multistage arrangement has equal dominant critical frequencies, you may think that the overall dominant critical frequency is equal to the critical frequency of each stage. This is not the case, however.
- When the dominant lower critical frequencies of each stage in a multistage amplifier are all the same. The dominant critical frequency can be calculated by :

$$f'_{cl(dom)} = \frac{f_{cl(dom)}}{\sqrt{2^{1/n} - 1}}$$

$$f'_{cu(dom)} = f_{cu(dom)}\sqrt{2^{1/n} - 1}$$

($n$ is the number of stages in the multistage amplifier)

# Questions